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Abstract: Background Pacing, defined as percentage changes of speed between successive splits, has been extensively studied in running and cycling endurance sports; however, less information about the trends in change of speed during cross-country (XC) ski racing is available. Therefore, the aim of the present study was to examine the effect of performance (quartiles of race time (Q), with Q1 the fastest and Q4 the slowest) level on pacing in the Vasaloppet ski race, the largest XC skiing race in the world. Methods For this purpose, we analyzed female (n = 19,465) and male (n = 164,454) finishers in the Vasaloppet ski race from 2004 to 2017 using a 1-way (2 gender) analysis of variance with repeated measures to examine percentage changes of speed between 2 successive splits. Overall, the race consisted of 8 splits. Results The race speed of Q1, Q2, Q3, and Q4 was 13.6 ± 1.8 , 10.6 ± 0.5 , 9.2 ± 0.3 , and 8.1 ± 0.4 km/h, respectively, among females and 16.7 ± 1.7 , 13.1 ± 0.7 , 10.9 ± 0.6 , and 8.9 ± 0.7 km/h, respectively, among males. The overall pacing strategy of finishers was variable. A small sex \times split interaction on speed was observed ($\eta^2 = 0.016$, $p < 0.001$), with speed difference between sexes ranging from 14.9% (Split 7) to 27.0% (Split 1) and larger changes in speed between 2 successive splits being shown for females ($p < 0.001$, $\eta^2 = 0.004$). A large performance \times split interaction on speed, with Q1 presenting the smallest changes of speed between splits, was shown for females ($\eta^2 = 0.149$, $p < 0.001$) and males ($\eta^2 = 0.169$, $p < 0.001$). Conclusion Male and fast XC skiers are more even pacers. Coaches and athletes should develop tailored sex- and performance-level pacing strategies; for instance, they should advise fast XC skiers to start fast and maintain their speed, rather than starting slowly and trying to make up time by going faster at times during the race.

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Original article

The effect of sex and performance level on pacing in cross-country skiers: Vasaloppet 2004–2017

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Abstract

Background: Pacing, defined as percentage changes of speed between successive splits, has been extensively studied in running and cycling endurance sports; however, less information about the trends in change of speed during cross-country (XC) ski racing is available. Therefore, the aim of the present study was to examine the effect of performance (quartiles of race time (Q), with Q1 the fastest and Q4 the slowest) level on pacing in the Vasaloppet ski race, the largest XC skiing race in the world.

Methods: For this purpose, we analyzed female ($n = 19,465$) and male ($n = 164,454$) finishers in the Vasaloppet ski race from 2004 to 2017 using a 1-way (2 gender) analysis of variance with repeated measures to examine percentage changes of speed between 2 successive splits. Overall, the race consisted of 8 splits.

Results: The race speed of Q1, Q2, Q3, and Q4 was 13.6 ± 1.8 , 10.6 ± 0.5 , 9.2 ± 0.3 , and 8.1 ± 0.4 km/h, respectively, among females and 16.7 ± 1.7 , 13.1 ± 0.7 , 10.9 ± 0.6 , and 8.9 ± 0.7 km/h, respectively, among males. The overall pacing strategy of finishers was variable. A small sex \times split interaction on speed was observed ($\eta^2 = 0.016$, $p < 0.001$), with speed difference between sexes ranging from 14.9% (Split 7) to 27.0% (Split 1) and larger changes in speed between 2 successive splits being shown for females ($p < 0.001$, $\eta^2 = 0.004$). A large performance \times split interaction on speed, with Q1 presenting the smallest changes of speed between splits, was shown for females ($\eta^2 = 0.149$, $p < 0.001$) and males ($\eta^2 = 0.169$, $p < 0.001$).

Conclusion: Male and fast XC skiers are more even pacers. Coaches and athletes should develop tailored sex- and performance-level pacing strategies; for instance, they should advise fast XC skiers to start fast and maintain their speed, rather than starting slowly and trying to make up time by going faster at times during the race.

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Keywords: Endurance exercise; Race speed; Sex; Sport performance; Winter sport

1. Introduction

Participation in cross-country (XC) skiing has increased rapidly during the last few decades worldwide, especially in the countries of north and central Europe (e.g., 42% of Finns participate in XC) and in countries with cold climates such as Canada, Russia, and the USA.¹ Considering the engagement of recreational XC skiers in the training process, a major concern of coaches and fitness trainers in this sport is to adapt

training practices that were previously established by competitive XC skiers² to the specific demands of recreational XC skiers. One of the training concerns of coaches and fitness trainers is to develop optimal pacing strategies during a race based on the performance level of the XC skiers they are coaching.³ However, limited information exists with regard to the effect of performance level on pacing in XC skiing.

The effect that sex, age, and race time have on pacing was examined in a sample ($n = 800$) of finishers in the Vasaloppet ski race (the largest XC skiing race in the world).⁴ The study showed a relatively more even pacing among females than among males, with the former presenting smaller decreases in speed than the latter during the race. Another recent analysis

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of the Vasaloppet ski race from 2012 to 2016 indicated that males had relatively more even pacing than females, and no difference was observed among age groups.⁵ The discrepancy between the 2 abovementioned studies should be attributed to their different samples because Carlsson and colleagues⁴ examined females and males with the same race times, whereas Nikolaidis and Knechtle⁵ analyzed all finishers. Furthermore, an analysis of 10 km and 15 km XC races showed that slower skiers presented larger decreases in speed during the race compared with the fastest skiers for males, but no effect of performance on pacing, according to the comparison between groups differing for race time, was observed for females.⁶

Although the abovementioned studies improved our understanding of pacing in XC skiing, the effect of sex and performance on pacing remains unclear. Limited information exists about whether fast and slow XC skiers differ in their pacing. Considering that the Vasaloppet ski race is the largest in the world,⁷ such knowledge could have a large practical impact, especially as it would be the first time examining this topic using such a large database. Therefore, the aim of the present study was to examine the effect of performance level and sex on pacing in the Vasaloppet race. Given the limited research on pacing strategies in XC skiing races,⁴ but the extensive literature on endurance running,^{8–11} we hypothesized that (1) fast XC skiers would present a relatively even pacing compared with their counterparts with lower performance levels and (2) males would have a more even pacing than females.

2. Materials and methods

2.1. Ethical approval

The Institutional Review Board of St. Gallen, Switzerland, approved this study. Since the study involved analysis of publicly available data, the requirement for informed consent was waived. The study was performed following the ethical guidelines of the Declaration of Helsinki.

2.2. The race

The Vasaloppet is the oldest and longest XC ski race in the world and has the highest rate of participation for all ski races.⁴ The race's full distance is 90 km, with the start in Sälen and the finish in Mora, and the race route includes 7 monitoring stations (Table 1). The difference in elevation between the start and finish is –185 m. The 7 stations, that is, checkpoints

where race times are recorded, were used to define 8 split distances and times. For instance, Split 2 was defined as the difference in kilometers between Station 2 and Station 1. The time duration of Split 2 was calculated as the difference between race time at Station 2 and Station 1. By combining the distance and duration of Split 2, we calculated the speed in Split 2. Change of speed (%) at each station was calculated using the following formula: $100\% \times (\text{speed in the following split} - \text{speed in the preceding split}) / \text{speed in the preceding split}$. For instance, change of speed (%) at Station 6 = $100\% \times (\text{speed in Split 7} - \text{speed in Split 6}) / \text{speed in Split 6}$.

2.3. Data sampling and data analysis

Data for the years 2004–2017 were obtained from the official race website (www.vasaloppet.se). Initially, 184,459 finishers were considered. We excluded the cases ($n = 540$) with at least 1 missing split time, which resulted in the final inclusion of 183,919 finishers (19,465 females and 164,454 males). Because differences in XC skiing race times between sexes have previously been shown,^{12,13} male and female finishers were classified separately in performance groups based on quartiles of race time (i.e., Q1, Q2, Q3, and Q4, with Q1 being the fastest time and Q4 being the slowest). The dependent variables were the race speed within splits and the change of speed, that is, between 2 successive splits. The independent variables were sex and performance group (Table 1). To study pacing strategies, we examined the variation of speed by split and the change of speed by station, that is, the difference in speed between 2 successive splits, as well as the roles of sex and performance group.

2.4. Statistical analysis

All data are presented as means and standard deviations. Figures were created using GraphPad Prism Version 7.0 (GraphPad Software, San Diego, CA, USA); all other statistical analyses were carried out using IBM SPSS Version 23.0 (IBM Corp., Armonk, NY, USA). One-way (2 gender) analysis of variance with repeated measures examined the effects of split (and station) and sex on race speed (and change of speed), where the within-subjects factor was split (and station) and the between-subjects factor was sex. Within each sex, differences among performance groups were tested using 1-way analysis of variance with repeated measures. Subsequent comparisons among performance groups were carried out using a *post hoc*

Table 1
Track profile showing the stations, their distance from the start, split distance, elevation, and change in elevation.

	Start	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	End
Name	Berga	Smågan	Mångsbodarna	Risberg	Evertsberg	Oxberg	Hökberg	Eldris	Mora
Distance from the start (km)	0	11	24	35	47	62	71	81	90
Split distance (km)	—	11	13	11	12	15	9	10	9
Elevation (m)	350	480	425	420	430	230	250	205	165
Change in elevation (m) ^a	—	+130	–55	–5	+10	–200	+20	–45	–40

Note: ^a Change in elevation was calculated as the difference between the elevation of 2 successive stations. For instance, the change in elevation during Split 1 was the difference between Station 1 and start, that is, $480 - 350 = 130$ m.

Bonferroni test. The magnitude of the differences among performance groups (effect size) was examined using partial η^2 and was evaluated as the following: minor ($0.010 < \eta^2 \leq 0.059$), moderate ($0.059 < \eta^2 \leq 0.138$), and major ($\eta^2 > 0.138$).¹⁴ Interquartile differences in speed for each split were calculated as $100\% \times (\text{speed of faster quartile} - \text{speed of slower quartile}) / \text{speed of slower quartile}$, for example, $Q1 - Q2 = 100\% \times (Q1 - Q2) / Q2$. The acceptable type I error rate was set at $p < 0.05$.

3. Results

3.1. Speed by sex and split

Males were shown to be faster than females (12.4 ± 3.1 vs. 10.4 ± 2.3 km/h, $p < 0.001$, $\eta^2 = 0.265$). The race speed of Q1, Q2, Q3, and Q4 was 13.6 ± 1.8 , 10.6 ± 0.5 , 9.2 ± 0.3 , and 8.1 ± 0.4 km/h, respectively, for females and 16.7 ± 1.7 , 13.1 ± 0.7 , 10.9 ± 0.6 , and 8.9 ± 0.7 km/h, respectively, for males. A major effect of split on speed was observed ($p < 0.001$, $\eta^2 = 0.512$), with speed ranging from 9.7 ± 3.5 km/h (Split 1) to 13.8 ± 3.1 km/h (Split 2) (Fig. 1). A minor sex \times split interaction on speed was shown ($p < 0.001$, $\eta^2 = 0.016$), with sex difference in speed ranging from 14.9% (Split 7) to 27.0% (Split 1) (Fig. 2). Males were faster than female XC skiers for each split ($p < 0.001$). This sex difference decreased across the race.

3.2. Change of speed by sex and station

A major effect of station on change of speed was observed ($p < 0.001$, $\eta^2 = 0.618$) (Fig. 3). The greatest increase of speed was shown at Station 1, that is, from Split 1 to Split 2 ($+48.8 \pm 24.4\%$), and the smallest increase of speed was shown at Station 7, that is, from Split 7 to Split 8 ($+6.1 \pm 6.2\%$). The smallest decrease of speed was found at Station 2, that is, from Split 2 to Split 3 ($-1.3 \pm 6.4\%$), and the largest decrease of speed was found at Station 5, that is, from Split 5 to Split 6

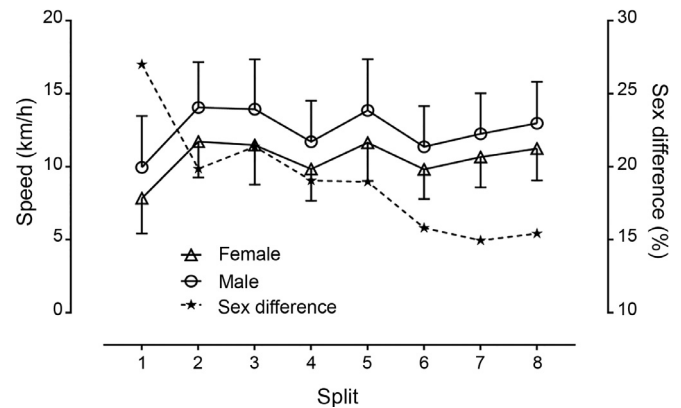


Fig. 2. Race speed of finishers by split and sex. Sex difference (%) was calculated as $100\% \times (\text{male's speed} - \text{female's speed}) / \text{female's speed}$. Error bars represent standard deviations. Sex difference was significant for each split at $p < 0.001$.

($-17.3 \pm 5.6\%$). A trivial sex \times station interaction on speed was observed ($p < 0.001$, $\eta^2 = 0.004$), with females presenting larger changes in speed than males at 4 stations (i.e., Stations 1, 2, 4, and 6) and smaller changes in speed at 3 stations (i.e., Stations 3, 5, and 7). The largest difference in change of speed between females and males was shown at Station 1, that is, from Split 1 to Split 2 ($+53.8 \pm 20.0\%$ for females and $+48.2 \pm 24.4\%$ for males). The smallest sex difference in change of speed was shown at Station 4, that is, from Split 4 to Split 5 ($+18.7 \pm 8.7\%$ for females and $+18.3 \pm 8.0\%$ for males).

3.3. Speed by performance group and split

A large performance group \times split interaction on speed was observed among females ($p < 0.001$, $\eta^2 = 0.149$) (Fig. 4A) and among males ($p < 0.001$, $\eta^2 = 0.169$) (Fig. 4B). This interaction showed that the differences (i.e., Q1-Q2, Q2-Q3, and Q3-Q4) in speed among performance groups (i.e., quartiles) varied

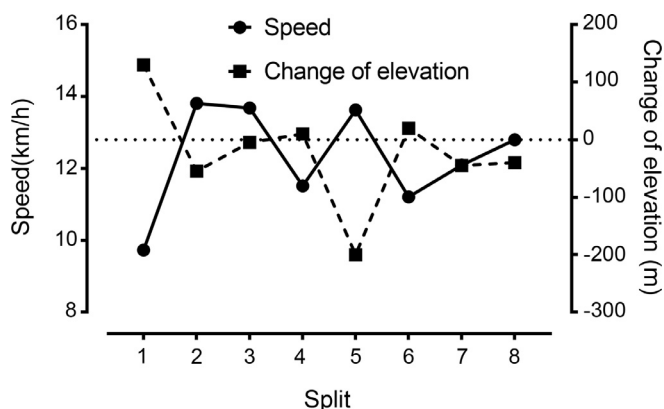


Fig. 1. Race speed and change of elevation by split. The horizontal dotted line represents 0 change of elevation. Race speed of split is calculated from the distance and time of the split. Change of elevation in the split was defined as the difference between the elevation of the following station and the preceding station. All splits differed for speed at $p < 0.001$.

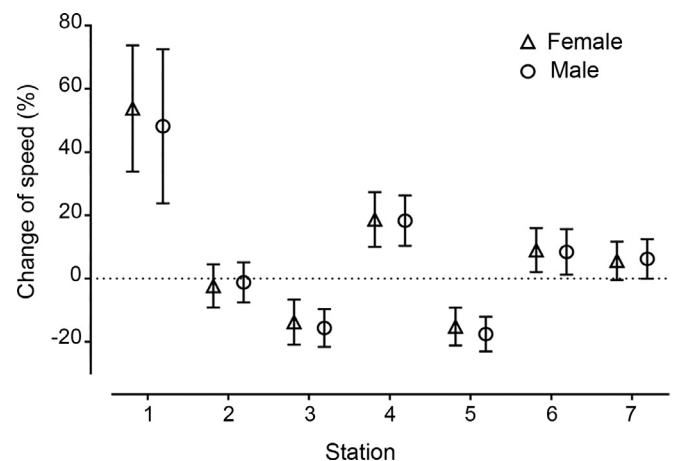


Fig. 3. Change of speed of finishers by station and sex. The horizontal dotted line represents 0. Error bars represent standard deviations. All stations differed for change of speed (%) from the preceding to the following split at $p < 0.001$. Females and males differed for change of speed (%) in all stations at $p < 0.001$.

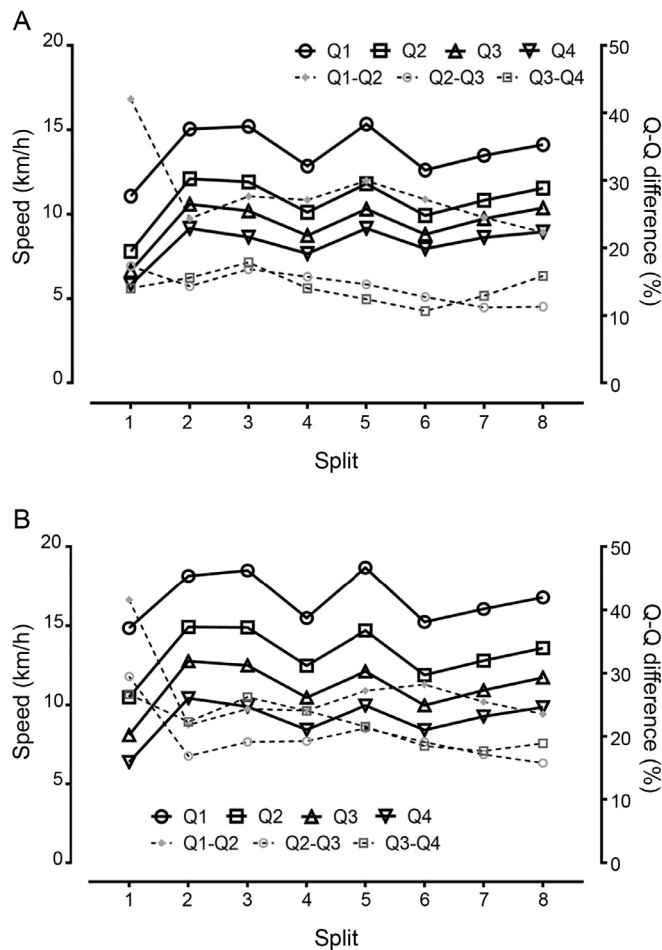


Fig. 4. Race speed of finishers by split in female (A) and male (B). Q = quartile; Q-Q = interquartile. Q-Q difference was calculated as $100\% \times (\text{faster quartile} - \text{slower quartile}) / \text{slower quartile}$. Interquartile differences in speed were significant at $p < 0.001$ for each split.

across race. In both sexes, the Q1-Q2 difference in speed was larger than Q2-Q3 and Q3-Q4 overall. In addition, the Q1-Q2 difference was the greatest in Split 1 and decreased the most from Split 1 to Split 2. That is, Q1 (i.e., the fastest quartile) and Q2 increased their speed from Split 1 to Split 2, and this increase was more pronounced in Q2 than in Q1.

3.4. Change of speed by performance group and station

An interaction (performance group \times station) on change of speed was observed for females (moderate magnitude, $p < 0.001$, $\eta^2 = 0.122$) (Fig. 5A) and for males (large magnitude, $p < 0.001$, $\eta^2 = 0.308$) (Fig. 5B). For both sexes, an overall trend was observed where the smallest changes of speed were presented in Q1 (i.e., the fastest females and males) and the largest in Q3 and Q4 (i.e., the 2 slowest performance groups). This trend was particularly verified in Stations 1, 2, 6, and partially in Station 7, but not in Stations 3, 4, and 5. That is, the fastest XC skiers demonstrated a more even pacing than their slower counterparts, especially in the first kilometers of the race.

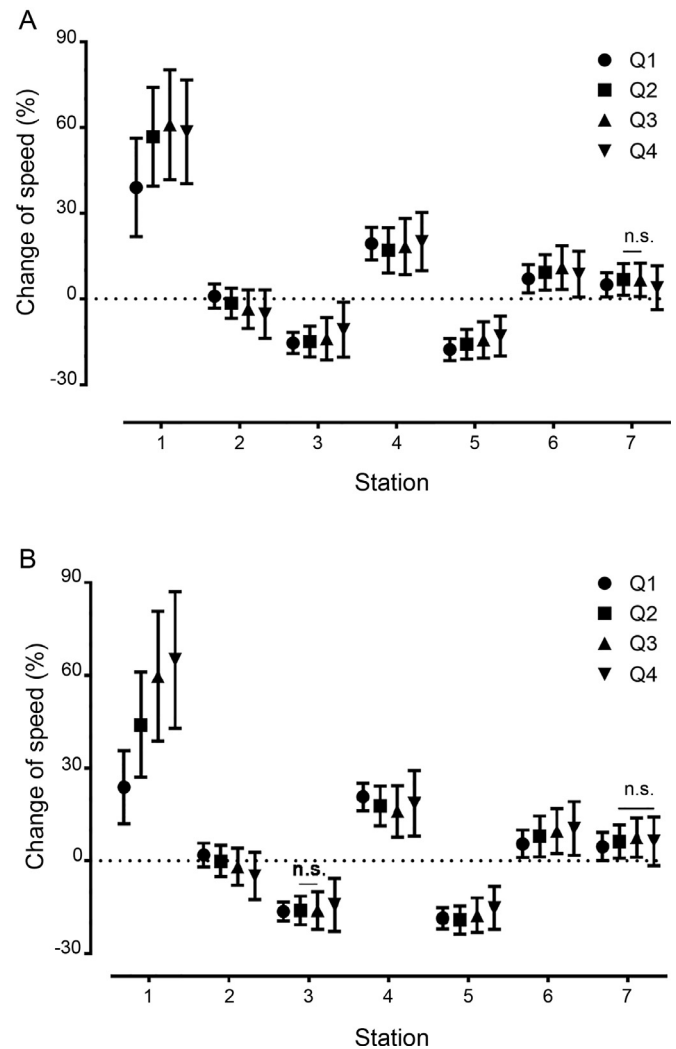


Fig. 5. Change of speed of finishers by split in female (A) and male (B). The horizontal dotted line represents 0. Error bars represent standard deviations. Performance groups differed for change of speed (%)—for instance, from the previous to following split—in all stations and for both sexes at $p < 0.001$, in all cases except if the difference is depicted as nonsignificant (n.s.).

4. Discussion

The main findings of the present study were that (1) XC skiers adopted a variable pacing strategy; (2) the difference in speed between the sexes ranged from 14.9% (Split 7) to 27.0% (Split 1), and greater changes of speed between 2 successive splits were observed for females; (3) for both sexes, a major performance \times split interaction on speed was shown, with Q1 presenting the smallest changes in speed; and (4) the fastest XC skiers started the fastest at Split 1 and presented the smallest increase of speed at Station 1, that is, from Split 1 to Split 2.

With regard to the classification of pacing strategies in endurance performance into negative, all-out, positive, even, parabolic-shaped, and variable pacing,¹⁵ the pattern of change in speed during the Vasaloppet ski race could be classified as variable, because the change of speed did not follow a consistent pattern throughout the race. It has been proposed that athletes tend to adopt a positive pacing strategy during endurance

events.¹⁵ An explanation for the fact that XC skiers adopted a variable instead of a positive pacing strategy in the Vasaloppet race might be the large changes in elevation between and within splits, where gravity resists the XC skiers during uphill climbs and propels them during downhill stretches. As shown in Fig. 1, these changes in elevation directly impact speed, and the relationship of these 2 parameters is inverse, that is, when there is an increase in elevation, the speed is relatively slow and *vice versa*.

Considering the effect of sex on pacing, a remarkable observation was that females presented greater changes in speed at the stations (i.e., % change from the preceding to the following split) than males. This observation indicated that males show a more even pacing, which was in partial agreement with the existing literature concerning XC skiing^{5,16} but not for other sports. For instance, a greater change in speed was found among females than among males in the Engadin Ski Marathon¹⁶ and in a previous study using fewer years (2012–2016) in the Vasaloppet race.⁵ In contrast to our present findings, it has been shown that females were better pacers (i.e., with more even pacing) than males in marathon running.^{9,10} This disagreement indicates a likely variation in the effect of sex on pacing among different endurance sports. A partial explanation for the pacing of females in skiing might be the practice of drafting,¹⁷ which can help XC skiers to save energy. It has also previously been reported that differences in pacing between the sexes in endurance sports might be due to some aspect of decision-making, such as overconfidence, risk perception, or willingness to tolerate discomfort.¹⁸ Furthermore, it has been observed that a more even pacing is associated with better performance in endurance sports; thus, the differences in performance might partially explain corresponding differences in pacing.¹⁹

In addition, concerning the effect of performance group on pacing, the superior performance of the fastest XC skiers at the start was accompanied by the smallest increase of speed at Station 1 (i.e., from Split 1 to Split 2), suggesting that fast XC skiers were characterized by a relatively more even pacing compared with their slower counterparts. This result was in agreement with studies on endurance running, which revealed relatively small changes in Speed among the fastest runners.^{8,11} For instance, among athletes competing in Olympic and World Championship marathons, female and male medalists maintained even-paced running from 10 km onward, whereas slower finishers dropped off the lead pack at approximately half distance.¹¹ In addition, among athletes competing in World Half Marathon Championships, the best males and females largely maintained their split speeds between 5 and 15 km, whereas slower athletes had decreased speeds from 5 km onward.²⁰ However, a unique characteristic in the Vasaloppet ski race was the striking differences in change of speed among performance groups at Station 1, for instance, from Split 1 to Split 2, in contrast with the subsequent Stations, where relatively small changes in speed were shown. As shown from the difference between Q1 and Q2 at Split 1, the smaller change in Speed of Q1 at Station 1 should be attributed to its superior speed at Split 1. An explanation for the quick

start of the fastest group in Split 1 might be that elite XC skiers exert high-intensity effort in the first large ascent (+130 m) in order to be placed in a good position in the leading group. On the contrary, the slowest group, consisting of recreational XC skiers, likely got stuck in the first ascent and did not pace according to their original pacing strategy.

The results of the present study are limited by the unique characteristics of the Vasaloppet ski race in terms of race distance and change in elevation; therefore, the results should be interpreted with caution when compared with other XC ski races. Moreover, it is acknowledged that other factors could also influence pacing, for example, the combination of glide wax and grip wax (at a recreational level) or glide wax (at an elite level), as well as quality of equipment, base grind, wax choice, and waxing procedure.²¹ Another factor that was not controlled for in the present study was the technique (double poling, diagonal stride, and kick double poling) of XC skiers, which might influence pacing since it has been shown to be related with performance level.^{22,23} In addition, due to the large sample size, many effects reached statistical significance at $p < 0.001$; this is the reason that we provided effect size value next to p value so one can evaluate the magnitude of the effects correctly. However, a strength of the study is the inclusion of all occurrences of the Vasaloppet race (2004–2017) for which all split times were available, resulting in one of the largest samples of XC skiers ever studied.

5. Conclusion

In the present study, we found a moderate effect among females and a major effect among males of performance on pacing in the Vasaloppet ski race. Our results highlighted that males have a more even pacing than females, which contrasts with findings in studies of marathon running, where females have been shown to be more even pacers. Moreover, the results indicated that fast XC skiers start the race with relatively fast speed in the first demanding (ascending) 11 km (Split 1) and increase their speed the least at Station 1 (i.e., from Split 1 to Split 2) compared with their slower counterparts. Slow XC skiers, however, showed the opposite trend (i.e., they start slow and increase their speed the most as the race progresses), which can be partially attributed to the massive start. These findings are of great practical importance considering the large number of XC skiers ($n > 13,000$) participating in the Vasaloppet every year. Given the association of pacing with performance in this sport,^{3,6} coaches and athletes should develop tailored sex- and performance-level pacing strategies; for instance, they should advise fast XC skiers to start fast and maintain their speed.

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Authors' contributions

BK conceived the idea of the overall project on pacing in cross-country skiing, supervised the data collection and contributed in the writing and editing of the manuscript; EV collected

the data; PTN conceived the idea of the article idea, performed the statistical analysis and drafted the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of the presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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